BRL

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PEAK OVERPRESSURE VS SCALED DISTANCE FOR TNT SURFACE BURSTS (HEMISPHERICAL CHARGES)

C. N. Kingery
B. F. Pannill

RDT & E Project No. 1M010501A00

BALLISTIC RESEARCH LABORATORIES
ABERDEEN PROVING GROUND, MARYLAND

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C. N. Kingery
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Terminal Ballistics Laboratory

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RDT & E Project No. 1M010501A006

ABERDEEN PROVING GROUND, MARYLAND

B A L L I S T I C R E S E A R C H L A B O R A T O R I E S

MEMORANDUM REPORT NO. 1518

CNKingery/RFPannill/paf
Aberdeen Proving Ground, Md.
April 1964

PEAK OVERPRESSURE VS SCALED DISTANCE FOR TNT SURFACE BURSTS (HEMISPHERICAL CHARGES)

ABSTRACT

This report contains a presentation of peak overpressure versus scaled distance values derived from empirical measurements made by Canada, the United Kingdom and the United States. The measurements were made on 5, 20 and 100 ton TNT surface bursts. The charges were hemispherical in shape and the instrumentation included overpressure versus time gages and the photo-optical shock front velocity technique for determining peak overpressure.

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OBJECTIVES

The primary objective of this report is to present a compilation of overpressure measurements obtained from a series of TNT detonations. For many years there has been a need for a reliable surface burst peak overpressure versus distance curve extending from 2000 psi to .01 psi. Curves presenting overpressure versus radial distance (measured and theoretical) have been available for many years for spherical charges detonated in free air. This is not true however, for surface burst overpressure curves which in general have been over a limited range of overpressure, and based on either small charges or charges fired under various environmental conditions, making reliable scaling difficult. It is the objective of this report to combine measurements made by Canadian, United Kingdom and United States scientists into one report which might be used as a standard for TNT surface bursts.

BACKGROUND

The Suffield Experimental Station (SES) working under the guidance of the Defense Research Board of Canada began a series of field experiments relating to blast and shock using yields of 5 tons of TNT in 1959. The U. S. was invited to participate in one of the trials in September 1959. We accepted this invitation, and sent a blast team from the Ballistic Research Laboratories (BRL) to establish a blast line and to measure the overpressure versus time at selected distances from ground zero. The preliminary results were reported in a technical paper published by SES with a very limited distribution[1]. The results obtained by the Canadian team were reported in Suffield Technical Paper No. 205[2] along with results of four other 5 ton shots. The Canadian results were primarily peak overpressure values obtained from a photo-optical technique.

In 1960 a 20 ton TNT test was conducted at SES and again the U. S. sponsored several projects. One of the major projects from the U. S. was the measurement of overpressure versus distance by BRL. The United Kingdom (UK) also participated with several projects, one of which was also to measure overpressure versus distance. A Tripartite blast line was established and the three countries placed various pressure transducers at similar distances along the blast line for comparison. The results

from the tripartite blast line were published in Suffield Report No. 203[3].

A third test in which the BRL participated was the 1961 Canadian 100 ton TNT trial. Here again Canada, the U. K. and the U. S. instrumented blast lines and recorded the overpressure versus time at selected distances from ground zero. The results from this test have not been published in final form by all participants although preliminary data is available. The final U. S. data are available in a BRL report[4] and the preliminary data from Canada were obtained from private correspondence[5]. Data from the U. K. are reported in reference (6) and have also been compiled in this report.

RESULTS

The values of peak overpressure measured by the various countries and presented in the referenced sources were all scaled to a one pound equivalent at standard sea-level conditions. A total of 273 data points was used in establishing the curve as presented in Figure 1. These points were punched on IBM cards as scaled distance (λ) versus scaled overpressure (P_s). (λ) is a scaled distance and equals $R/W^{1/3}$ where R = actual distance in feet and W = yield in pounds. Therefore, λ is equal to R for a one pound charge. The logarithms corresponding to these data points were computed, and by a method of least squares the coefficients for a polynomial equation were derived. The result is:

$$\ln P_s = 7.0452041 - 1.6277561\,X - .27399088\,X^2 - .065973136\,X^3 + .0065412563\,X^4 + .0048236399\,X^5 - .020072553\,X^6 + .00301904\dots\,X^7 - .0001598\dots\,X^8 \quad (1)$$

where $X = \log \lambda$
with λ values from 0.5 to 440.

This equation, while fitting the points well over the range of values given, would be misleading if used in the very low pressure region (below 0.2 psi). Therefore, all values beyond a λ of 40 were processed through the computer, assuming an exponential decay and the following equation was derived for the low pressure range.

$$P_s = 226.61762\,\lambda^{-1.4065913} \quad (\ )$$

where $40 < \lambda < 1000$.

Equation 1 and 2 were combined to produce the values listed in Table I. Selected values of λ were put into equation 1 and values of peak overpressure were computed from $\lambda = .50$ to $\lambda = 70$. Equation 2 was used from $\lambda = 75$ to $\lambda = 1000$. The resulting pressure versus distance values calculated from equation 1 and 2 are listed in Table I and plotted in Figure I. It is felt that this curve is the best empirical curve available to date.

SCALING

To use the table or plotted curve for predicting peak overpressure versus distance for other TNT yields at other than standard sea level conditions, standard scaling procedures should be used. The scaling factor S_d for distance may be calculated from

$$S_d = \left[W \frac{14.696 \text{ psi}}{P_A} \right]^{1/3} \qquad (3)$$

where W = Yield in pounds

P_A = Ambient atmosphere at altitude (psi).

Therefore λ times S_d will give the new distance.

When scaling the peak overpressure to be expected where the ambient atmosphere is other than 14.696 psi a scaling factor S_p should be used. The factor S_p may be calculated from

$$S_p = \left[\frac{P_A}{14.696} \right] \qquad (4)$$

where P_A = Ambient atmospheric pressure at altitude (psi). Therefore S_p times the peak overpressure listed in the table or taken from the curve will give the new pressure value.

COMPARISONS

In an effort to determine the reliability of the values computed from the equations and the measured values the following method of comparison was established. The scaled overpressures versus distances (λ) were compared with calculated overpressures at a similar scaled distance λ. The comparison consisted of establishing the difference (plus or minus) between the two overpressures and then calculating the percentage or relative error between the computed value and the scaled measured value. The positive relative errors were summed and divided by the number of values to establish the mean positive relative error. The same procedure was used to establish the mean negative relative error. From these two values one can determine how well the computed values compare with the measured values on a percentage basis.

There were 45 datum points used from the 5 ton shot and of these 27 points were positive with positive relative error of 7.48 percent. There were 18 negative points with a relative error of 4.86 percent. This implies of course that 60 percent of the data fell an average of 7.48 percent above the curve and 40 percent of the data fell an average of 4.86 percent below the curve.

There was a total of 140 datum points compiled from the 20 ton shot. Of these 64 were positive with a mean positive relative error of 4.12 percent and 76 were negative with a mean negative relative error of 7.20 percent. Therefore 45.7 percent of the measured values were an average of 4.12 percent above the computed values while 54.3 percent fell an average of 7.20 percent below the computed values.

From the 100 ton shot a total of 88 datum points was used. There were 45 points positive with a mean relative error of 8.20 percent and 43 points negative with a mean relative error of 6.44 percent. This implies that approximately 51 percent of the measured points fell an average of 8.20 percent above the computed values and 49 percent of the measured points fell an average of 6.44 percent below the computed values.

For a final comparison a total of 273 datum points, compiled from the measurements made on the three shots, was used. There were 136 points positive with a mean relative error of 6.14 percent and 137 points negative with a mean relative error of 6.65 percent. This means approximately 50 percent of the measured points fell an average of 6.14 percent above the computed values while 50 percent fell an average 6.65 percent below the computed values.

Since there are some isolated points which indicate large relative errors and tend to outweigh the smaller values listed an investigation of the frequency distribution of the points was made and the results are presented in Table II. From the table it can be seen that approximately two thirds of all datum points lie within the two average relative error values of +6.14 percent and -6.65 percent.

C. N. Kingery

C. N. KINGERY

B. F. Pannill

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2. Groves, T. K. Air Blast Peak Overpressure from 5 Ton TNT Ground Burst Hemispherical Charges. Suffield Technical Paper 205, 1961.

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4. Kingery, C., Keefer, J., and Day, J. Surface Air Blast Measurements from a 100 Ton TNT Detonation. Ballistic Research Laboratories Memorandum Report 1410, 1962.

5. Letter dated 15 March 1962 reference SES 1601-12-1 (P&MS) to C. Kingery transmitting overpressure versus distance curves for the 100 Ton Trial.

   Letter dated 23 February 1962 transmitting pressure versus time curves recorded on the 100 Ton Trial.

6. James, D. J. SES 100 Ton TNT Blast Trial - Suffield, Alberta, August 1961, 1/40th Scale Experiment to Assess the Effect of Nuclear Blast on the London Underground System. AWRE Report No. E2/62, November 1962.

TABLE I

OVERPRESSURE vs. SCALED DISTANCE

DISTANCE λ FT./LB.$^{1/3}$	OVER-PRESSURE PSI	OVER-PRESSURE ATM.
.50	3149.9277	214.33912
.55	2781.2537	189.25243
.60	2471.0154	168.14204
.65	2208.8227	150.30094
.70	1985.6567	135.11545
.75	1794.1976	122.08748
.80	1628.5464	110.82243
.90	1357.9630	92.40358
1.00	1147.3430	78.07179
1.10	979.9653	66.68245
1.25	786.5415	53.52078
1.50	564.7510	38.42889
1.75	419.7423	28.56167
2.00	320.7123	21.82310
2.25	250.7734	17.06406
2.50	200.0081	13.60970
2.75	162.2958	11.04354
3.00	133.7117	9.09851
3.25	111.6599	7.59798
3.50	94.3778	6.42201
3.75	80.6412	5.48729
4.00	69.5828	4.73481
4.50	53.1643	3.61760
5.00	41.8400	2.84703
5.50	33.7565	2.29699
6.00	27.8152	1.89270
6.50	23.3370	1.58798
7.00	19.8870	1.35323
7.50	17.1779	1.16888
8.00	15.0143	1.02166
9.00	11.8195	.80427
10.00	9.6147	.65424
11.00	8.0286	.54631
12.50	6.3672	.43326
15.00	4.6653	.31746
17.50	3.6491	.24831
20.00	2.9842	.20306
22.50	2.5189	.17140
25.00	2.1761	.14807

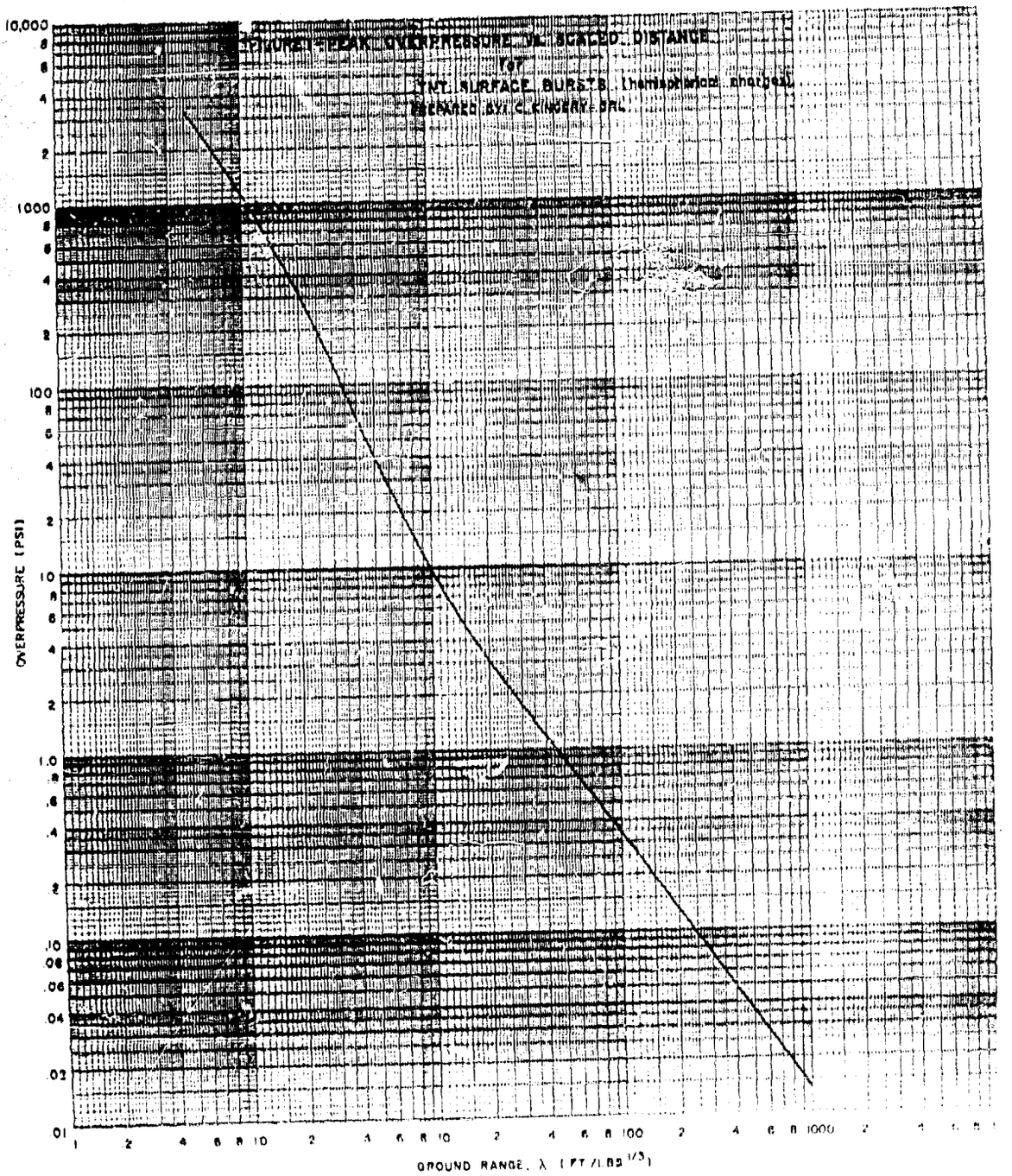
DISTANCE λ FT./LB.$^{1/3}$	OVER-PRESSURE PSI	OVER-PRESSURE ATM.
27.50	1.9134	.13020
30.00	1.7056	.11606
32.50	1.5369	.10458
35.00	1.3971	.09507
37.50	1.2793	.08705
40.00	1.1785	.08019
45.00	1.0149	.06906
50.00	.8876	.06040
55.00	.7857	.05346
60.00	.7023	.04779
65.00	.6328	.04306
70.00	.5742	.03907
75.00	.5222	.03553
80.00	.4769	.03245
90.00	.4041	.02750
100.00	.3484	.02371
110.00	.3047	.02073
125.00	.2546	.01732
150.00	.1970	.01340
175.00	.1586	.01079
200.00	.1314	.00894
225.00	.1114	.00758
250.00	.0960	.00653
275.00	.0840	.00571
300.00	.0743	.00506
325.00	.0664	.00452
350.00	.0598	.00407
375.00	.0543	.00369
400.00	.0496	.00337
450.00	.0420	.00286
500.00	.0362	.00246
550.00	.0317	.00216
600.00	.0280	.00191
650.00	.0250	.00170
700.00	.0226	.00154
750.00	.0205	.00139
800.00	.0187	.00127
900.00	.0158	.00108
1000.00	.0137	.00093

TABLE II

DISTRIBUTION OF DATUM POINTS WITHIN SELECTED RELATIVE ERROR RANGE

POSITIVE RELATIVE ERROR	NUMBER OF POINTS	NEGATIVE RELATIVE ERROR	NUMBER OF POINTS	RANGE OF RELATIVE ERROR	NUMBER OF POINTS	PERCENT OF TOTAL POINTS*
PERCENT+		PERCENT-		PERCENT ±		PERCENT
1	23	1	20	1	43	15.7
2	18	2	18	2	79	29.0
3	16	3	17	3	112	41.0
4	10	4	15	4	137	50.0
5	11	5	10	5	158	57.8
6	7	6	6	6	171	62.5
7	4	7	3	7	178	65.0
8	5	8	9	8	192	70.2
9	6	9	2	9	200	73.1
10	9	10	5	10	214	78.2
11	5	11	5	11	224	82.0
12	4	12	4	12	232	85.0
13	6	13	4	13	242	88.5
14	0	14	4	14	246	90.0
15	5	15	0	15	251	92.0
16	1	16	1	16	253	92.5
17	1	17	1	17	255	93.5
18	1	18	0	18	256	93.6
19	3	19	1	19	260	95.0
20	1	20	3	20	264	96.6
21	0	21	2	21	266	97.4
22	0	22	1	22	267	97.6
23	0	23	2	23	269	98.4
24	0	24	1	24	270	98.9
25	0	25	1	25	271	99.0
26	0	26	1	26	272	99.5
27	0	27	1	27	273	100.0

* TOTAL NUMBER OF POINTS WAS 273



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UNCLASSIFIED Report

Air blast - Determination
Blast effects - Measurements
Trinitrotoluene - Blast

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